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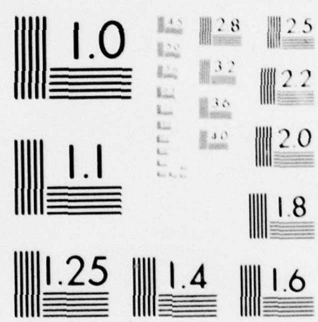

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USE OF THE JET FUEL THERMAL OXIDATION TESTER (JFTOT) FOR PREDICTING DIESEL FUEL PERFORMANCE

by

Maurice E. LePera

and

Fred McCaleb

March 1978

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An investigation was conducted to define the feasibility for using the Jet Fuel Thermal Oxidation Tester (JFTOT) as a laboratory predictor to assess diesel fuel quality relative to operating performance. A methodology was subsequently established to define diesel fuel performance relative to filter pressure differentials at limiting operating temperatures. A variety of diesel fuels and candidate additives were screened using this approach. The modified JFTOT did effectively screen and discriminate between the fuels as a result of their composition, hydrocarbon quality, and possible contaminants.

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CONTENTS

TABLES

USE OF THE JET FUEL THERMAL OXIDATION TESTER (JFTOT) FOR PREDICTING DIESEL FUEL PERFORMANCE

1. **Introduction.** Fuel-related field performance problems have been experienced in the past with fuel-filter clogging and injector fouling occurring in various Army diesel-engine-powered equipment. Conventional specification tests for diesel fuels have not been able to define/predict with any certainty whether diesel fuels would exhibit those tendencies towards fuel-filter plugging or injector fouling. As a result, the desirability and need for a diesel fuel "laboratory performance" technique relative to fuel-filter plugging and injector fouling was indicated. The initial attempt in developing a laboratory performance technique was provided in an interim report which described the modification of the ASTM-CRC Fuel Coker apparatus.[1] Although this technique showed some promise in differentiating between fuel quality, the poor repeatability and large sample size requirements were obvious disadvantages. However, the recently developed Jet Fuel Thermal Oxidation Tester (JFTOT) appeared to be a viable candidate for this investigation. The JFTOT, described by ASTM D3241, was developed for predicting the thermal oxidation stability of aviation turbine fuel. As this method is capable of developing high fuel temperatures through a standard filter at standard flow rate, the JFTOT was considered to be a technique having potential capabilities for laboratory performance testing of diesel fuel. Results of the initial investigation are described herein.

2. **Details of Test.** The JFTOT apparatus was investigated as a diesel fuel discriminator using no modifications to its present configuration. A general summary of the JFTOT procedure is provided in the Appendix. For the initial assessment of the feasibility of the JFTOT, several diesel fuels were obtained for evaluation in terms of differentiation in their quality.

The samples obtained included fuels which had been evaluated previously in the ASTM-CRC Fuel Recycle Coker study[2] diesel fuel procured under Federal Specification VV-F-800a Grade DF-2, commercial ASTM 2-D diesel fuels obtained from service stations, and diesel fuels obtained from refinery sources.

Because of multiple variables in the JFTOT procedure, a methodology had to be established for differentiation of diesel fuel quality. The JFTOT currently employs failure, or test-limiting, criteria; namely, exceeding the pressure differential (Δ P) across the test filter which is maximum at 127 mm mercury and/or exceeding

[1] Maurice E. LePera, CCL Interim Report No. 321, "Thermal-Oxidative Stability of Automotive Diesel Fuels," February 1973.

[2] Maurice E. LePera, Interim Status Report on Recycle Fuel Coker Program, CRC-Diesel Fuel & Fuel Systems Group Meeting, 10 January 1974.

the surface discoloration/deposition on the preheater tube. Since the previous work with the ASTM-CRC Fuel Recycle Coker had shown the pressure differential limitation to provide greater test repeatability and was more indicative of the mode of failure occurring in field, the 127-mm mercury pressure differential limit was selected. A trial-and error test methodology was initially employed to establish test operating parameters. Preliminary experimentation involved evaluating diesel fuel samples tested previously on the ASTM-CRC Fuel Recycle Coker. This was followed by evaluation of the effects of operating procedure changes to increase the overall severity of the test and then the establishment of JFTOT procedure/scheme to discriminate the quality level of diesel fuel.

3. **Discussion of Data.** A sampling of the diesel fuels evaluated previously in the ASTM-CRC Fuel Recycle Coker was selected initially. Of the five fuels selected, one was considered unsatisfactory in view of its low rating relative to thermal instability (CCL-F-802), one was marginal (CCL-F-822), and the other three possessed high *thermal stability ratings* (CCL-F-801, -803, and -817). The five fuels were evaluated subsequently in the JFTOT apparatus using 487°F as an operating temperature representative of the three temperature regimes employed previously in the ASTM-CRC Fuel Recycle Coker. The results of the JFTOT evaluation versus those obtained previously with the Recycle Coker are shown in Table 1. With the exception of CCL-F-802, the agreement of data was somewhat lacking.

As these were the first data obtained on the JFTOT, further experimentation was needed. Based upon the data developed previously,[3] the variations in recycling were considered subsequently. The intent here was to determine whether additional thermal stressing would maximize the intensity of results to be obtained with the JFTOT apparatus. Various test variations using the JFTOT apparatus were then considered, ranging from multiple passes through the JFTOT to thermal stressing of samples prior to the JFTOT test. Two diesel fuels were used for this experiment: a sample of test diesel fuel procured under Federal Specification VV-F-800b (diesel fuel from the POL Test Area at MERADCOM) and a sample of commercial Diesel 2-D obtained from a local service station outlet. The results of these JFTOT procedural variations and modifications are shown in Table 2. These data revealed that preheating temperature below the Δ P break point did not cause samples to fail at temperatures below their initial breakpoint.

[3] Maurice E. LePera, CCL Interim Report No. 321, "Thermal-Oxidative Stability of Automotive Diesel Fuels," February 1973.

Table 1. Comparison of Initial JFTOT Data with that Obtained Using Recycled CFR Fuel Coker

Sample No.	Recycle Fuel Coker,[1] Δ P (inches) Across Filter @ 149°C/204°F	177°C/232°F	260°C/316°F	JFTOT Results Δ P (mm HG)[3] @ 253°C	Tube Color Ratings ASTM	TDR Spun
CCL-F-801	NR[2]	0.2	0.3	3 in 50 min	–	38
CCL-F-802	10.7	12.3	–	127 in 57 min	4	40
CCL-F-803	–	0.1	0.2	3 in 50 min	2	27
CCL-F-817	–	0.9	1.4	NR	4	38.5
CCL-F-822	–	4.4	10.3	NR	4	32.5

1 Test temperature identify Preheater/Test Filter combination used for that test sequence.

2 NR – No measurable rise in Δ P during the test interval.

3 Δ P "failure" occurs after differential exceeds 127 mm. Test duration is 150 minutes.

– No reading obtained at temperature indicated.

Table 2. Effect of Additional Thermal Stress/Recirculation on Increasing Severity of JFTOT Test

Sample No./ Description	Preconditioning Employed Prior to JFTOT	JFTOT Test Temperature, °C (°F)	Δ P Failure,[1] (minutes)	Tube Rating TDR Spun
MERDC Test DF-2	None	253(487)	12.9	23.8
"	200 ml recirculated in JFTOT @ operating temperature	253(487)	14.1	24.8
"	Preheating for 7 hr @ 212°F, followed by recirculation two times through JFTOT @ 480° and 475°F	249(462)	NR[2]	40.8
"	Preheating for 7 hr @ 212°F, followed by recirculation once through JFTOT @ 480°F	246(475)	76.8	35.0
"	Preheating for 7 hr @ 212°F	249(480)	81.7	35.0
Commercial 2-D Source M	None	218(425)	NR	23.0
"	Preheating for 16 hr @ 212°F	218(425)	NR	20.3
"	Preheating for 7 hr @ 420°F	218(425)	NR	32.0

1 ΔP "failure" occurs after differential pressure exceeds 127 mm.

2 NR – No measurable rise in ΔP during 150-minute test.

At this point, it was decided that a "standardized" test methodology was needed to establish the feasibility for using the JFTOT to discriminate quality of diesel/distillate fuels. The JFTOT in its present configuration was developed to correlate with the ASTM-CRC Fuel Coker for rating the performance of aviation fuels. Since the majority of field problems or diesel fuels have involved fuel filter plugging, it was decided to use the JFTOT's differential test filter pressure rating as the limiting pass-fail criteria; some measurable "ΔP rise" within the first 30 minutes of operation. Once this temperature range was found, an additional test was performed to validate the limiting temperature. In addition to this "ΔP failure at a test temperature," the level of deposition on the preheater tube could be employed to provide supplemental data. Using this approach, a series of fuels was evaluated. Initially, three of the diesel fuels tested previously (Table 1) as well as five commercial 2-D diesels samples and two samples of diesel fuel meeting VV-F-800b were evaluated using this methodology. The results are shown in Table 3. In addition to these, additional samples obtained in conjunction with a depot fuel deterioration program were also analyzed and the results are shown in Table 4. Since the data developed showed a wide range in "thermal quality," it was decided to identify the repeatability of data. Table 5 presents the repeatability of data obtained for ten representative samples. It is interesting to note that excellent repeatability was shown in terms of ΔP failure time and tube ratings in all except one instance. In this case, the commercial 2-D diesel gave a 100 percent increase in ΔP failure time over that obtained initially. No explanation could be given for this anomaly.

One further experiment was conducted in an effort to derive some meaning of the JFTOT tube ratings as they apply to these fuels. Several fuels were tested at two temperature conditions and at differing test deviations to assess the effects of these on the resultant JFTOT deposit rating. The results of this experiment are shown in Table 6. The TDR spun deposit rating developed for each sample essentially was a function of the time and temperature conditions. The data show no obvious relationship of TDR spun deposit rating and ΔP failure time. These deposit ratings accumulating over a long period have been hypothesized to be indicative of diesel injector fouling. In addition to the experiments presented, all JFTOT heater tubes were weighed before and after the tests in an attempt to quantify the TDR spun deposit. Most of the tubes showed neglible weight gain indicating little if any relationship between weight and deposition ratings.

One last experiment, in investigating the JFTOT for diesel fuel application, involved the evaluation of additives relative to their potential deleterious effects. Two types of additives were evaluated; namely, Vapor Corrosion Inhibitors (VCI) and Friction Reducer polymers. The VCI materials were evaluated, as these are at times added to fuel tanks during preservation procedures and their deleterious effects during subsequent use/exercising of the vehicle have been suspect relative to the diesel fuel

Table 3. JFTOT Data on Various Diesel Fuel Samples

Sample No.	Description of Fuel	JFTOT Test Temp., °C (° F)	ΔP Failure 127 mm, minutes[1]	Tube Ratings ASTM	TDR Spot	TDR Spun
CCL-F-803	APG Test Diesel Fuel	253(487)	>150	<2	27.0	31.0
"	"	281(538)	"	PEACOCK	33.0	34.5
CCL-F-801	APG Test Diesel Fuel	192(375)	"	<2	23.0	24.5
"	"	226(438)	"	>4	31.0	33.0
"	"	253(487)	57	>4	40.0	41.0
CCL-F-817	APG Test Diesel Fuel	192(375)	>150	2	25.5	27.0
"	"	226(438)	"	>4	31.0	32.5
–	MERDC Test DF-2	177(350)	"	<4	31.5	32.5
–	"	253(487)	12.9	2	23.8	25.2
–	Commercial 2D, Source E	353(667)[2]	>150	PEACOCK	37.0	41.0
–	Commercial 2D, Source H	253(488)	107	>4	32.5	33.0
	"	260(500)	70	>4	33.7	35.0
	"	288(550)	18	4	33.2	36.0
–	Commercial 2D, Source M	343(650)	>150	>4	50.0	>50.0
–	Commercial 2D, Source S(1)	290(537)	110	>4	39.3	41.0
–	Commercial 2D, Source S(2)	290(537)	58	>4	37.2	39.0
–	DF2, Underground Tank, *Quantico Base*	232(450)	150	>4	28.0	28.8
	"	274(525)	"	>4	34.5	36.0
–	DF2, Vehicle Tank, Quantico Base	274(525)	15.2	4	34.0	35.2

[1] Samples showing ">150" indicate no change occurred in ΔP during 150 minutes.

[2] This was JFTOT's maximum limit.

– Number not given these samples.

Table 4. JFTOT Data on Refinery and Depot Samples

Sample No.	Description of Fuel	JFTOT Test Temp., °C (° F)	ΔP Failure 127 mm, minutes[1]	Tube Ratings		
				ASTM	TDR Spot	TDR Spun
AL-6678	DF-2, Refinery Sample (T)	260(500)	66	>4	34.7	35.0
AL-6746	DF-2, Refinery Sample (S)	301(575)	68	>4	45.8	47.2
AL-6175	DF-2, Refinery Sample	253(587)	65	>4	41.0	42.0
AL-6716	DF-2, Refinery Sample (A)	290(537)	63	>4	49.4	49.4
AL-6625	DF-2, Refinery Sample	246(475)	40	<2	26.0	28.2
"	"	308(587)	22	>4	31.0	33.0
"	"	316(600)	16	<3	28.0	30.0
AL-6626	"	322(612)	83	>4	50.0	50.0
AL-6630	"	231(448)	105	>4	33.4	34.0
"	"	253(487)	22	3	33.0	34.0
"	"	282(540)	8	1	24.0	26.0
AL-6574	Ref DF-2 for FTM 341	301(575)	84	>4	48.0	48.6
AL-6712	DF-2, Fort Hood Facility	343(650)	>150	>4(B)	>50	> 50
AL-6718	DF-2, Sharpe Army Depot	260(500)	46	>4	44.2	45.0
AL-6757	DF-2, Sacramento Army Depot	290(637)	55	4	38.0	40.3
AL-6731	DF-2, New Cumberland Army Depot	338(640)[2]	>150	>4(B)	>50	> 50
AL-6704	DF-2, Tooele Army Depot	343(650)	>150	>4	>50	> 50
AL-6706	DF-2, Anniston Army Depot	274(525)	66	>4	38.4	38.8
AL-6707	DF-2, Seneca Army Depot	274(525)	102	<4	35.0	36.2
AL-6684	DF-2, Letterkenny Army Depot	274(525)	93	>4	36.1	37.8
AL-6713	DF-2, Yuma Proving Ground	357(675)	>150	>4(B)	>50	> 50
AL-6624	DF-2, USAF Sample	361(681)[3]	>150	>4(B)	>50	> 50

[1] Samples showing ">150" indicate no change in ΔP occurred during the 150 minutes.

[2] Although JFTOT was set @ 650°F, operating temperature reached only 640°F.

[3] This was JFTOT temperature limit.

Table 5. Repeatability of JFTOT Data

Sample No.	Description of Fuel	JFTOT Test Temp., °C	ΔP Failure 127 mm, minutes	Tube Rating TDR Spun Deposit
–	DF-2, Quantico USMC Base	274	18	31.2
	"	274	15	35.2
–	Commercial 2D, Source H	288	18	36.0
	"	288	18	38.2
–	Commercial 2D, Source E	260	92	28.7
	"	260	86	34.2
–	Commercial 2D, Source S(1)	290	49	35.5
	"	290	110	39.3
–	Commercial 2D, Source S(2)	290	58	34.2
	"	290	52	37.2
–	Commercial 2D, Source C	260	96	31.2
	"	260	103	33.7
–	Ref. DF-2 for FTM 341	288	103	35.7
	"	288	106	28.5
AL-6707	DF-2/Seneca Depot	274	86	34.2
	"	274	90	37.7
AL-6684	DF-2/Letterkenny Depot	274	80	36.2
	"	274	105	36.0
AL-6678	DF-2, Refinery Sample	260	64	34.8
	"	260	67	34.5

– Numbers not given these samples.

Table 6. Effect of Temperature and Test Duration on JFTOT Tube Ratings

Sample No./Description	Effects at Low Temperature			Effects at High Temperature		
	Test Temp., (°C)	ΔP Failure *127 mm* minutes*	*TDR Spun* Deposit	Test Temp., (°C)	ΔP Failure 127 mm minutes*	TDR Spun Deposit
Commercial 2D, M	218	>150	23.0	343	>150	>50
Commercial 2D, H	246	>150	32.2	288	18	33.2
Commercial 2D, S(1)	267	>150	38.0	281	49	41.2
Commercial 2D, S(2)	267	>150	41.0	281	52	34.2
Commercial 2D, F	226	>150	25.0	343	>150	37.0
DF-2, Underground Tank Quantico	226	>150	23.0	274	>150	34.5
DF-2 Vehicle Tank, Quantico	226	>150	21.2	274	15.2	34.0
CCL-F-822 (DF-2)	226	>150	21.3	253	>150	33.5
CCL-F-817 (DF-2)	226	>150	31.0	253	>150	38.5
CCL-F-803 (DF-2)	253	>150	27.0	281	>150	33.0
CCL-F-802 (DF-2)	226	>150	31.0	253	57	40.0
CCL-F-801 (DF-2)	226	>150	28.0	281	41	48.0
MERDC Test DF-2	198	>150	31.5	253	13	23.8

* Samples showing ">150" indicate no change in ΔP occurred during 150 minutes.

delivery and injection systems. The friction reducer additives were evaluated to assess whether they contributed to any deposition or ΔP failure. The results of this additive evaluation are shown in Table 7. The two VCI materials had about equal influence on the diesel sample at the lower operating temperature. When evaluated at the higher operating temperature, however, the one product caused ΔP failure to occur within 73 minutes indicating it to be thermal sensitive. The three friction reducer additives were evaluated at one temperature only. Their effect on ΔP failure was varied; however, all three produced an increased level of deposit over that of the neat fuel which was interpreted as being deleterious.

During the numerous experiments with the JFTOT, a noteworthy anomaly was evidenced. This effect involved the inability to reach the maximum high temperature limit with all diesel fuels which were tested. More specifically, in the temperature range of 630° to 700°F, the JFTOT tended to stabilize at temperatures of 640°, 667°, and 681°F, respectively, although in each case, *the controls were set at 700°F.* Although the JFTOT is designed to operate up to 700°F, this heat-limiting anomaly may be a result of inadequate heat transfer because of heater contaminants affecting the heat transfer and deposition on the preheater tube.

Table 7. Effect of Various Inhibitors on Thermal Stability of Diesel Fuel

Sample Tested	JFTOT Test Temperature, °C	Time to ΔP Failure, Minutes	Preheater Tube Deposit Rating	
			ASTM No.	TDR Spun Deposit
Diesel Fuel A (Neat)	253	150	PEACOCK	35.0
Diesel A + 1% vol VCI[1]	253	86	3	41.6
Diesel A + 1% vol VCI[2]	253	87	4	30.0
Diesel Fuel B (Neat)	343	150	4	50
Diesel B + 1% vol VCI[1]	343	73	4	50
Diesel B + 1% vol VCI[2]	343	150	4	50
Diesel Fuel C (Neat)	260	106	2	28.5
Diesel Fuel C + 60 PPM Candidate Friction Reducer E[3]	260	86	4	33.2
Diesel Fuel C + 60 PPM Candidate Friction Reducer S[3]	260	150	4	42.8
Diesel Fuel C + 60 PPM Candidate Friction Reducer C[3]	260	103	3	33.7

[1] MIL-P-46002 Preservative supplied by Company 1.

[2] MIL-P-46002 Preservative supplied by Company 2.

[3] Friction reducer additives, which are high molecular weight range polymers, have been proposed as a means to reduce the turbulent drag phenomena occurring during pipeline movements of petroleum products and crude oil.

4. Conclusions.

The JFTOT apparatus, investigated to define its potential application for diesel fuels, was found to discriminate within a wide range of diesel fuel samples which were representative of field, refinery, depot, suspect, and commercial quality. The ΔP failure temperature and time to reach that point were used to differentiate the quality between the various diesel fuels. Failure temperatures ranged from approximately 450°F to above 650°F for the samples evaluated, whereas some did not fail within the temperature limitations of the JFTOT. The average ΔP failure point for diesel fuels was found to be approximately 525°F.

Preheating, recycling, and re-running at temperatures below the ΔP failure point did not appear to affect the limiting temperature significantly. Experimentation with additive materials revealed the JFTOT procedure to provide a means for predicting whether any deleterious effects relative to thermal instability would occur with introduction of the additive. It was difficult to place significance in the deposit color data obtained in these tests because of the operational procedure employed; that is, looking at measurable increases in the differential pressure across the test filter. The preheater tube discoloration or lacquering indicated, however, a loss in heat transfer and the susceptibility of certain components in the fuel to be thermally unstable.

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APPENDIX

SUMMARY OF JFTOT PROCEDURE

1. In establishing the ΔP failure point for diesel fuel, an initial sample is incrementally stressed from a low to a high temperature to identify the relative range of failure. The failure range is where a significant rise/increase in the filter pressure differential is evidenced within the initial 30 minutes of operation. Following this, two or three subsequent samples must be evaluated to obtain a definitive ΔP failure point for the fuel in question.

2. The sample size is 600 ml per test which requires 2.5 hours of operation.

3. The fuel pretreatment requires filtration through a sample layer of general-purpose retentive-quality filter paper. Following this, the sample is aeriated for 6 minutes at 1.5 liters per minute air-flow rate.

4. The sample is isolated in a pressure container; the container is attached to test machine; and the system is pressurized with nitrogen to 500 lb/in^2.

5. The sample passes through a prefilter (a 0.45-micron filter on supportive screen) at a flow rate of 3.0 ml/minute, by a polished heater tube (color data obtained from tube surface), out through a 17-micron nominal porosity precision filter located just downstream from the heater tube, and through a metering pump back to an isolated reservoir above the sample in pressure vessel.

6. The temperature of heater tube is automatically controllable up to about 700°F.

7. An automatic recorder records the pressure difference (in mm Hg) before and after the 17-micron precision filter. These samples were considered as failed at 125 mm Hg when the pressure alarm sounded, rather than at 250 mm Hg when the machine automatically shuts down.

8. The polished heater tube is washed with hexane; then the tube deposit color data are obtained. The Mark 8 TDR (Tube Deposit Rater) is an electronic optical instrument and reads spun and/or spot deposit ratings on a meter dial. The older Colorator compares color on the tube with the ASTM Standard Colors in ASTM D1660.